Bridging Safety Gaps in Combustible Dust Management – Lesson and prevention strategies from past incidents

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BECAUSE SO MUCH IS AT STAKE™

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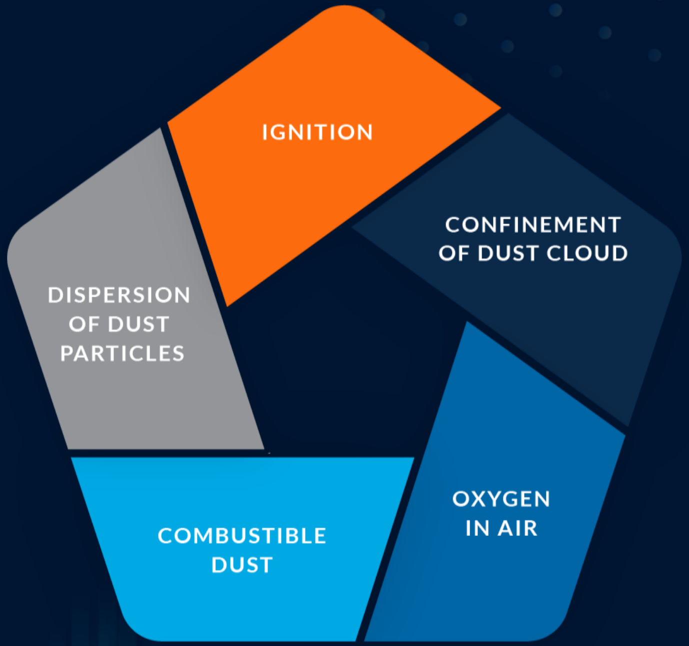
- Founded in 1945
- World HQ in Blue Springs, Missouri USA
- Over 1200 employees worldwide
- Manufacturing in US, Canada, UK, Belgium and Regional offices in 10 other countries
- Systems Manufactured –
  - *Over-pressurization*
  - *Explosion protection*
  - *Fire protection*

Explosion Pentagon



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Bridging Safety Gaps in Combustible Dust Management

Key Themes:

- Safety gaps in dust management
- Lessons from past incidents (e.g., Didion Milling, USA)
- Prevention strategies aligned with NFPA, ATEX, and SS 667:2020 standards

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What is Combustible Dust?

“particulate solid that presents a flash-fire or explosion hazard when suspended in air” - NFPA

- Historically, dusts were defined as particles that were 420 microns or smaller (passing a U.S. No. 40 Standard Sieve).
- If the material can form a dust cloud when agitated or disturbed, it should be addressed as a Combustible Dust – even if it is larger than 420 micron.

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Why is Combustible Dust a Hazard?

The rate of combustion of a material depends on particle size, and smaller particles have increased rates of combustion.

Normally, slow-burning material can create flash fires if particles are sufficiently small and suspended in air.

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Dust Testing – Flammable Properties

- The first step in managing combustible dust hazards is understanding the material properties.

- Material properties are often provided by the vendor, in textbooks, in NFPA standards, or in databases.

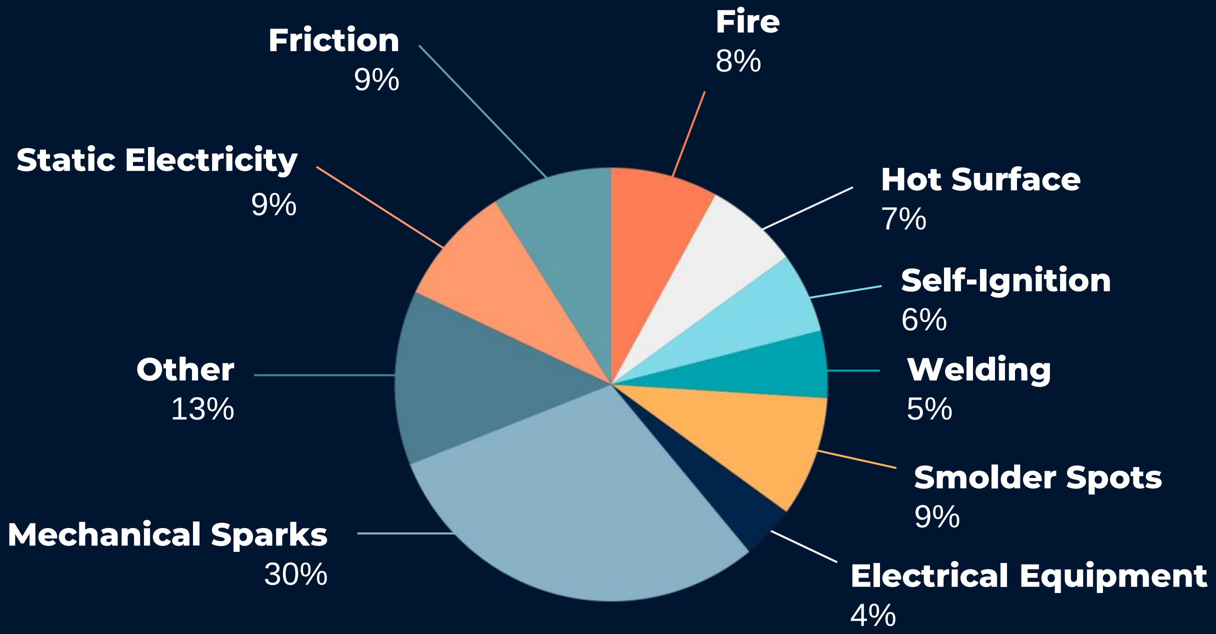
- Testing should be conducted when:
  - No data is available
  - The particle size or moisture content is different than published data
  - Mixtures are being handled

Common Dust Tests

- Screening (Go / No Go)
- Severity (Kst & Pmax)
- MEC (Minimum Explosive Concentration)
- MIE (Minimum Ignition Energy)
- MIT (Minimum Ignition Temperature of a dust layer)
- MAIT (Minimum Auto Ignition Temperature of a dust cloud)
- LOC (Limiting Oxygen Concentration)
- Percent Combustible Material
- Dust Burn Rate
- Volume Resistivity Test (aka Charge Relaxation or Bulk Resistivity)

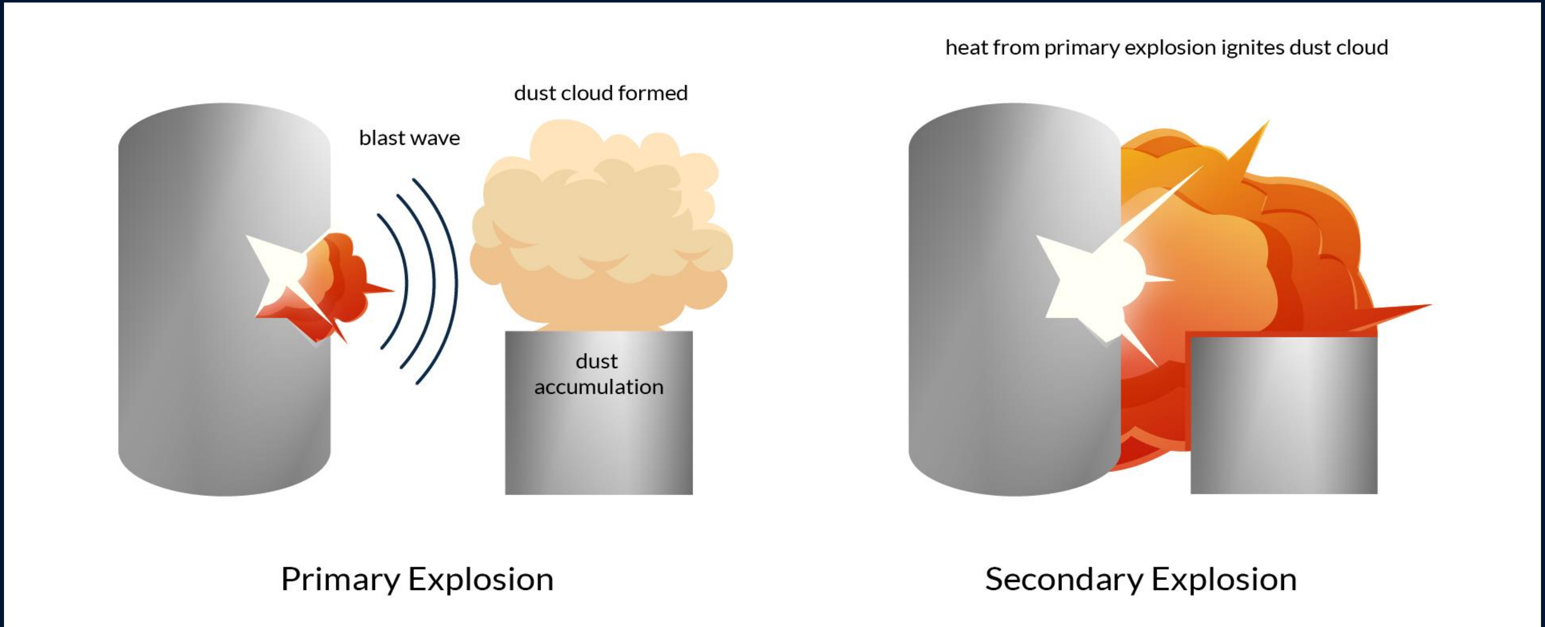
	Dust Test Required	Data is Used to Define
1 Is the dust explosive?	Screening (Go/No-Go)	Materials in the process susceptible to a dust explosion
2 How explosive is the dust?	Severity (Kst & Pmax)	Maximum energy and rate of an explosion if ignition occurs
3 Where may dust explosion hazards exist?	MEC - Minimum Explosible Concentration	Minimum dust concentration for ignition
	LOC - Limiting Oxygen Concentration	Lowest oxygen concentration for combustion
4 How sensitive is the dust to ignition?	MIE - Minimum Ignition Energy	Lowest spark energy required for ignition
	MIT (Layer) - Minimum Ignition Temperature (Layer)	Lowest temperature for a dust layer to ignite
	MIT (Cloud) - Minimum Ignition Temperature (Cloud)	Lowest temperature for a dust cloud to ignite

Ignition Source Statistics



Source: BIA report 11/97

Primary and Secondary Explosions



The concentrations needed for a dust explosion are rarely seen outside of process vessels, but dust layers can create a real hazard

Source: Grainger Info Library

Key Safety Gaps

- **Combustible Dust Data Deficiencies:**
  - Lack of comprehensive data on explosion characteristics
- **Control of Ignition source**
  - Control as per powder properties or test data
- **Inadequate Hazard Recognition:**
  - Overlooked risks in hidden areas like ductwork
- **Poor Maintenance and Housekeeping:**
  - Dust accumulation and ineffective cleaning
- **Equipment Interconnectivity Issues:**
  - Missing isolation devices, leading to propagation of explosions
- **Combustible dust training**
  - In-house training program for all levels

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Case study – Didion Milling

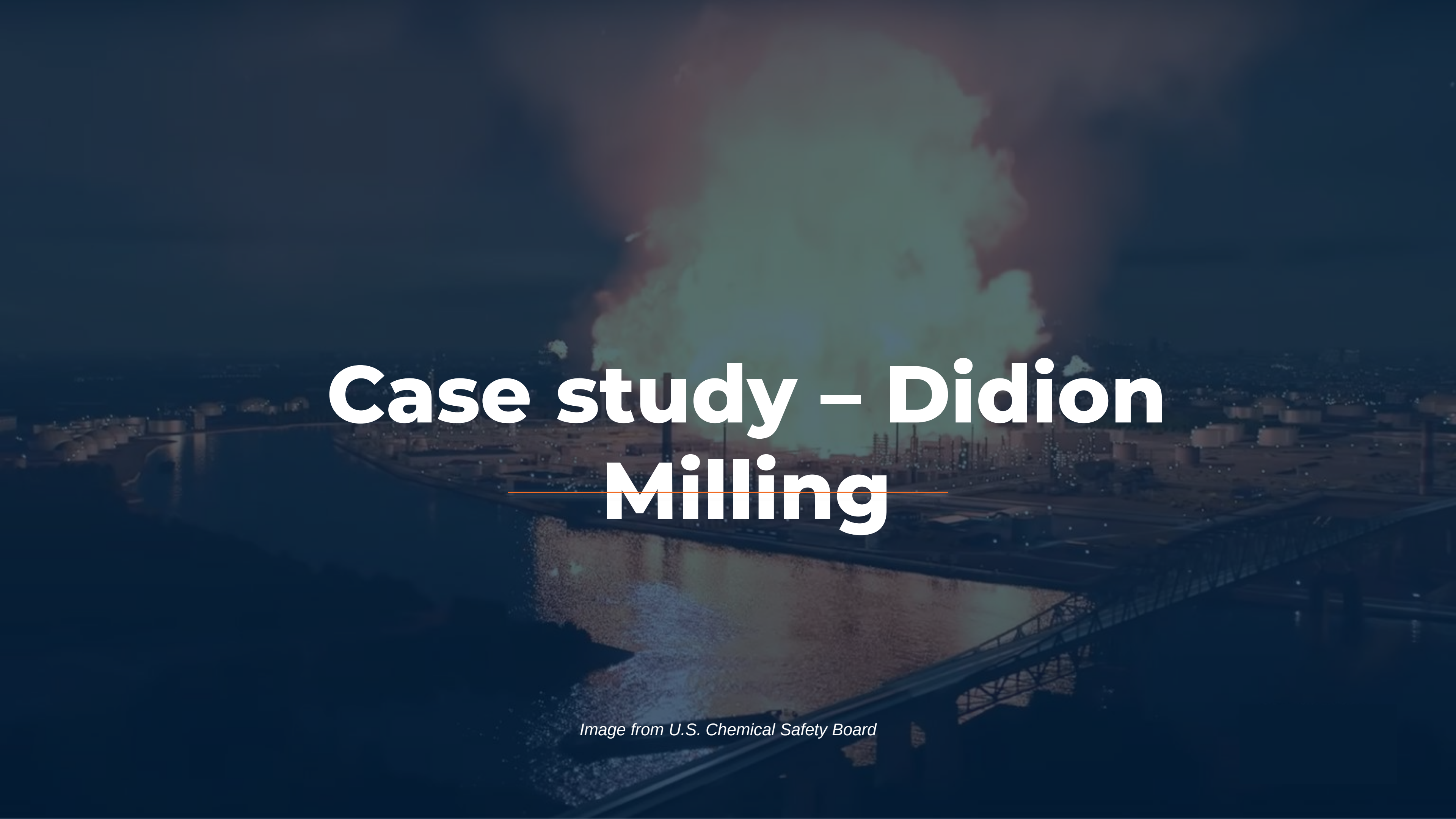

Image from U.S. Chemical Safety Board

Didion Milling

- Before May 31, 2017
- Cambria, WI
- Corn Dust
- Started at rotary gap mill, spread through the process equipment, explosions in dust collection equipment. Secondary explosions occurred throughout.
- 5 fatalities
- 14 injuries

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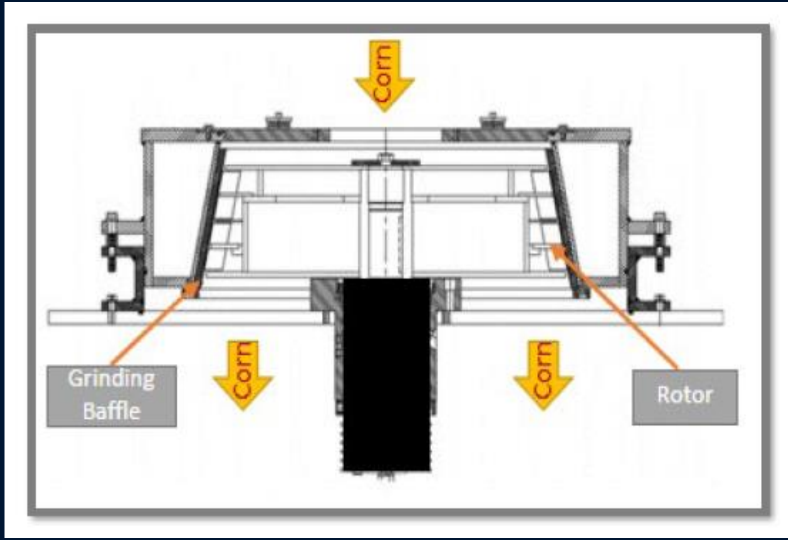
Didion Milling – Processing Equipment -Bran system



Cross section of a gap mill rotor and grinding baffle.
(Credit: Bauermeister; annotations by CSB)

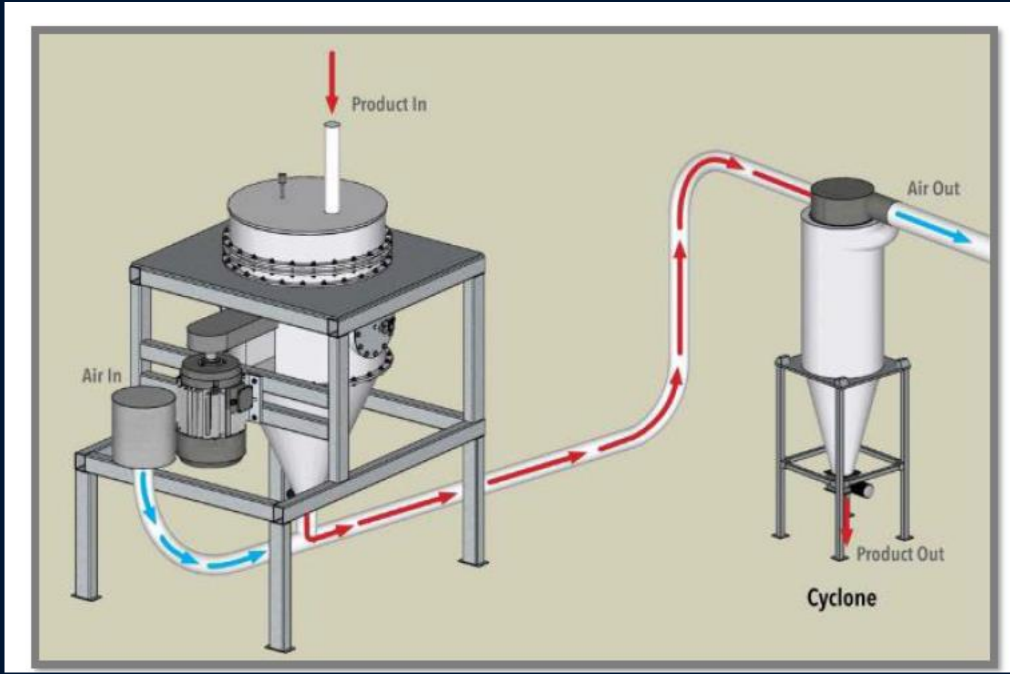


Diagram of South gap mill (South BM) and South BM discharge cyclone.
(Credit: CSB)

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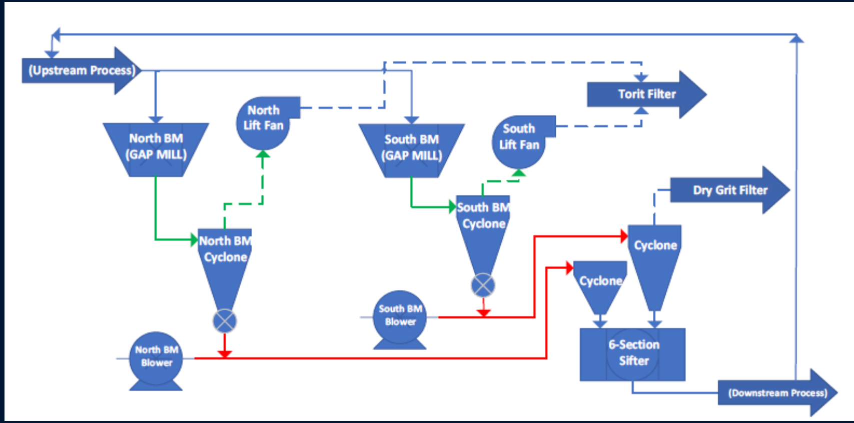
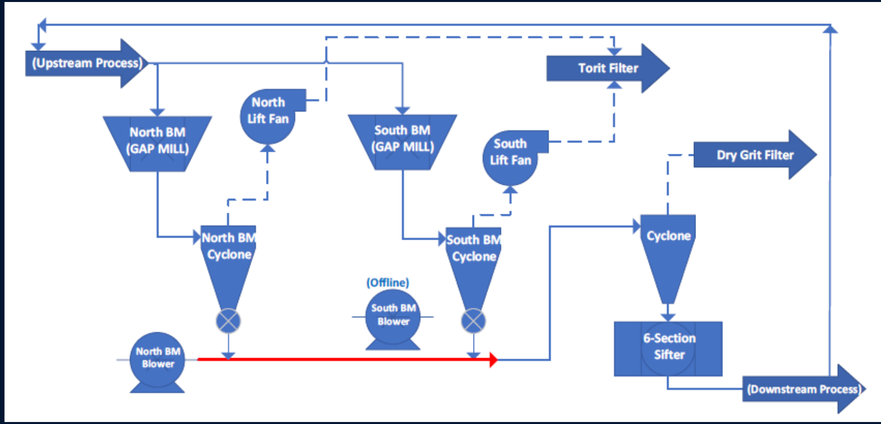
Didion Milling – Conveying line - MOC



Typical localized bran system process flow for North and South BMs. Vacuum pneumatic conveying lines are shown in green,and pressure pneumatic conveying lines in red. (Credit: CSB)



Temporary line (Credit: CSB)

Didion Milling – Incident analysis

The likely incident progression involved a series of events and phenomena, which can be described in these steps:

1. A smoldering nest developed in the Bran process, likely downstream of the South BM.
2. A primary explosion (Explosion 1) occurred inside Bran process equipment, likely located in 1B.
3. The primary explosion propagated inside the interconnected process equipment.

4a. The first secondary explosion (Explosion 2) occurred on 1B.

4b. Within a few seconds of Explosion 2, the Dry Grit Filter overpressured and released a fireball.

5a. A series of secondary explosions begins throughout the mill buildings, resulting in significant building damage and collapse.

5b. At approximately the same time, a deflagration propagated from the Dry Grit Filter back toward other process equipment through piping and ductwork.

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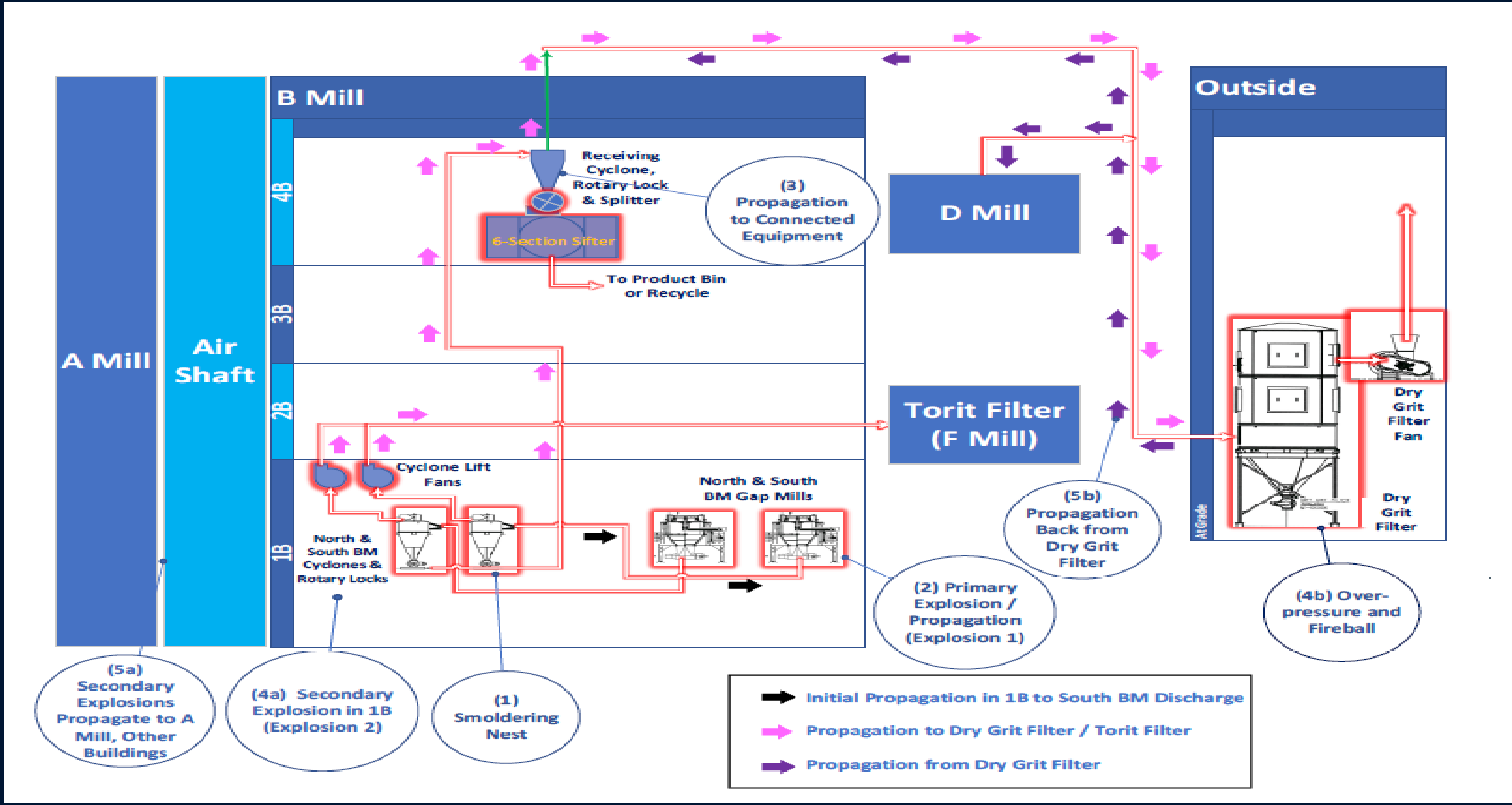
Didion Milling – Incident analysis



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Didion Milling – **1-Smouldering nest**

’The smouldering nest can simply be a lump of material that accumulates inside process equipment or adheres to a surface inside the process. Burning embers and lumps of material are common ignition sources in dust explosions. Smouldering or flaming particulate embers and smouldering nests can be produced by frictional heating, such as from milling equipment”

- 30 minutes before the first explosion smoke was first observed just outside B Mill
- There was no clear smoke source identified and no visible flames were observed until after the air intake filter blew off downstream of the South BM.
- No employees shut down the Bran process or performed any further investigation to determine where material inside the process was smouldering before the incident occurred. The search was external to the process equipment only, which was common practice at Didion before the incident.

The CSB concludes that, although the precise location could not be determined, a smouldering nest likely developed in equipment downstream of the Bauermeister gap mills in 1B, and likely initiated the incident.

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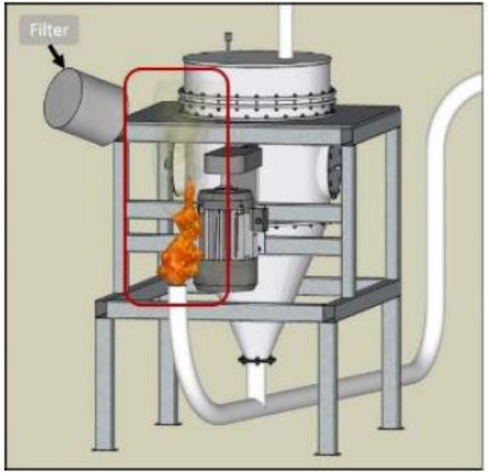
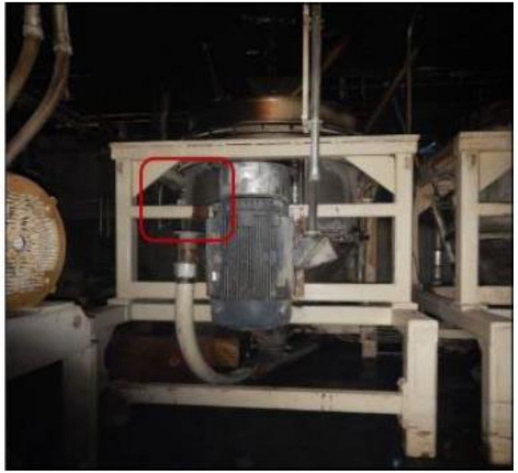
Didion Milling – **2 - Primary explosion 1**

"The CSB concludes that either an oscillating flame front or a series of small explosions spread burning material throughout the Bran process piping on 1B and accelerated a localized smouldering nest into a deflagration."

- Employees heard a huge boom and saw the air intake filter blow off the south BM transfer line to the south cyclone. Corn dust material and flames were noted coming out of the air intake for the transfer line.
- Employee B noted that the flame was visible for several seconds, was "sucked back in," and then reappeared – Indicative of an oscillating flame.
- Rae (1973) and Eckhoff et al. (1987) have performed research on oscillating flame front behaviour
- The same behaviour was observed in the south BM discharge.





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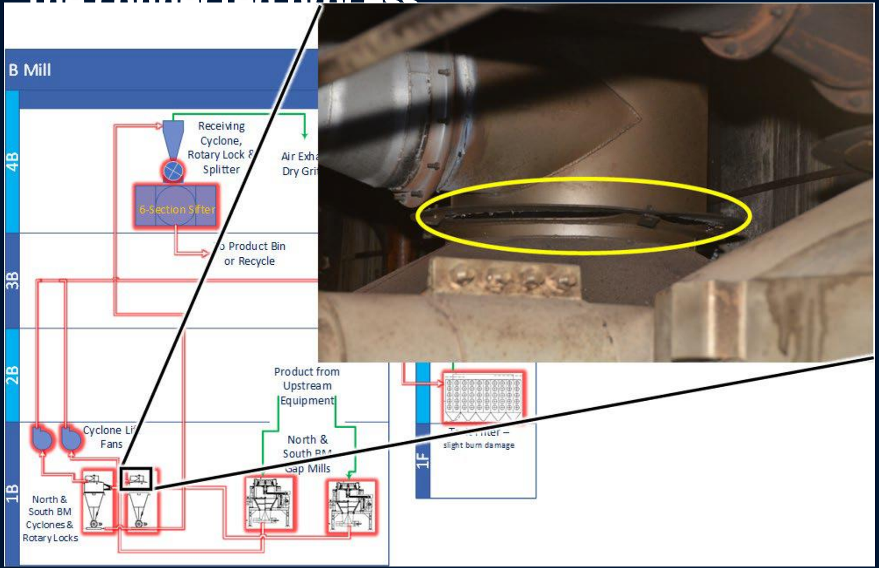
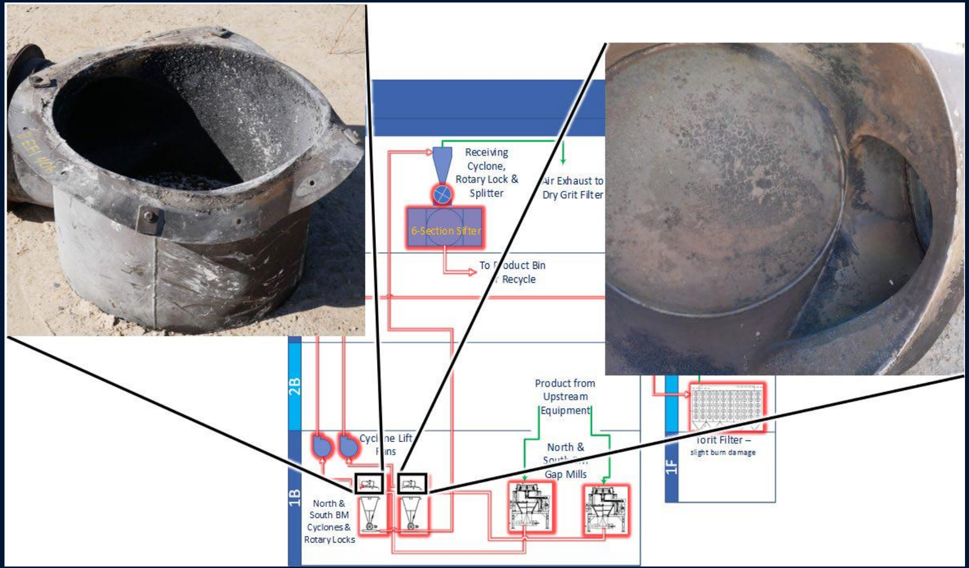
Didion Milling – 3 Primary explosion Propagation

‘The CSB concludes that an explosion downstream of the South Gap Mill in 1B occurred, which propagated through the North and South BM Cyclones and continued to propagate throughout the connected process.”



Top (discharge) section of South BM receiving cyclone, separated from body at flange (circled) from an overpressure inside the equipment. (Credit: Didion inset; CSB background)



Burn damage inside the top of North (left) and South (right) BM Cyclones. (Credit: CSB)

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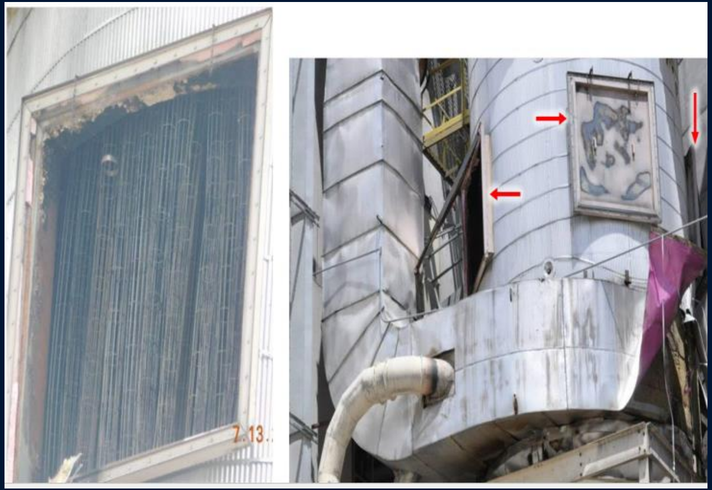
Didion Milling – Dry grit filter explosion

'The CSB concludes that the deflagration that began in 1B propagated to the Dry Grit Filter.."



Dry Grit Filter damage. Internal damage (left). The filter socks were burned away, leaving only the metal cages. Deflagration vents (right, red arrows) stuck open and with burn damage. (Credit: Didion, annotations by CSB

Examples of Dry Grit Filter ductwork and blower damage (red arrows). Inlet duct blackened (shown during demolition, left) and exhaust to atmosphere, including blower (right). (Credit: left, Didion with annotations by CSB; right, CSB)

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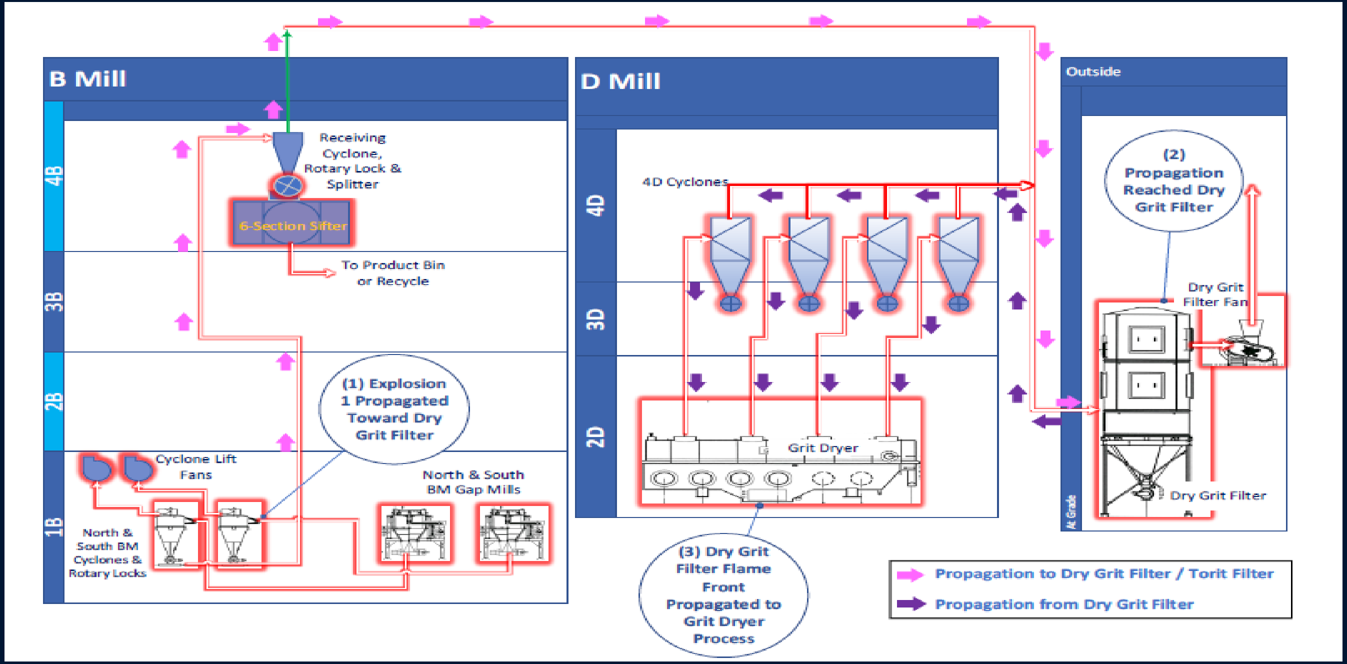
Didion Milling – Propagation from Dry Grit Filter

‘The CSB concludes that a deflagration in the Dry Grit Filter propagated to other previously uninvolved parts of Didion’s processes, which allowed explosions and fire to continue to spread throughout the mill processes..”



Potential path for propagation from 1B to Dry Grit Filter (pink arrows) to (simplified) Grit Dryer system (purple arrows). Known internal fire damage is highlighted red. (Credit: CSB)

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Didion Milling – Secondary Explosion

"The CSB concludes that the primary explosion in 1B and the ensuing propagations lofted fugitive dust and spread secondary explosions throughout the mill facility."

- Process material blew out of the filter process piping and lofted into the air.
- Explosion directional analysis and building collapse analysis indicate that the air supply shafts between A Mill and B Mill allowed explosions to propagate upward from 1B throughout A Mill and B Mill.

4B air shaft damage (red arrows) and shaft opening into 4B (red box) in B Mill interior, pre-demolition. The 4B wall panels detached from the B Mill structure during the incident. (Credit: Didion, annotations by CSB)

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Safety Issues

CSB identified several safety issues and gaps:

Process Hazard Recognition	Process Safety Information
Dust Hazard Analysis	Management of External Audits and Inspections
Structural Design for Combustible Dust Hazards	Emergency Preparedness
Fugitive Dust Management	Personal Protective Equipment
Management of Change	Process Safety Leadership
Incident Investigation	Regulatory Coverage of Combustible Dust

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PROCESS HAZARD RECOGNITION

Didion's process designs lacked several safeguards and did not follow well-known design good practices, which if followed, could have prevented the incident. Deficiencies included

1. IDENTIFYING COMBUSTIBLE DUST – Didion did not recognize that many of its products and waste streams were combustible dusts
2. EQUIPMENT INTERCONNECTIVITY - Didion did not recognize that interconnecting equipment through dust collectors could present a deflagration propagation hazard
3. DUST COLLECTOR EXPLOSIBILITY - incorrectly calculated the combustible dust concentrations in its dust collectors
4. IMPROPER DUCTWORK SYSTEMS DESIGN AND VERIFICATION - Did not recognize that proper ductwork systems design and verification were crucial for safe dust collector operation

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PROCESS HAZARD RECOGNITION

1) IDENTIFYING COMBUSTIBLE DUST

- The CSB requested that Didion provide all analytical reports depicting initial characterization test result for combustible dusts. Didion was unable to provide any such testing report, but did provide dust collector calculations and Safety Data Sheets (SDSs).
- The SDS included several other warning languages for storage, electrostatic, Conditions to avoid etc
- The source for the data published in its SDSs were not available.

Dust explosion properties

Pmax	7.9 bar
dP/dT	397 bar/s
Kst	180 bar·m/s
Minimum explosible concentration (MEC)	120 - 140 g/m3
Minimum Ignition Energy (MIE) - dust cloud	500 - 1000 mJ
Minimum Ignition Temperature (MIT) - dust cloud	770 - 788 °F (410 - 420 °C)

Flammability limits in air, upper, % by volume Flammability limits in air, lower, % by volume	WHEN DISPERSED INTO THE AIR IN SUFFICIENT CONCENTRATIONS GRAIN DUST CAN EXPLODE IN THE PRESENCE OF AN IGNITION SOURCE. DO NOT ALLOW DUST TO BECOME DISPERSED INTO THE AIR, EVEN BY THE EXTINGUISHING AGENT. MINIMUM EXPLOSIVE CONCENTRATION IS 55 G/M3 . HOWEVER, MOISTURE CONTENT, PARTICLE SIZE, CALORIC PROPERTIES, AND SPECIFIC INGREDIENTS ALSO AFFECT THE EXPLOSIVENESS OF GRAIN DUST.

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PROCESS HAZARD RECOGNITION

1) IDENTIFYING COMBUSTIBLE DUST

- As per NFPA and ATEX standards particle sizes less than 500 microns are considered combustible dust.
- Historically, NFPA standards 2008 edition of NFPA 61, defined ''Any finely divided solid material 420 micros or less considered as combustible dust''. This likely explains Didion's calculations' past references to only particles smaller than 425 or 420 microns
- For comparison, CSB collected samples and performed analyses all the samples was below 425 microns

Material	Wt Percent under 425 microns (Didion)[b]	Wt Percent under 150 microns (Didion)	Vol Percent under 425 microns (CSB)	Vol Percent under 150 microns (CSB)	Vol Percent under 75 microns (CSB)
Bran Product 8480	100	95.2	99.1	80.4	52.9
Yellow Corn Flour 4300	100	99.9	98.4	72.6	48.2
Fine Yellow Corn Bran 8010	100	97.0			
Low Moisture Pregel Flour 7403[c]	100	95.0			
Medium Viscosity Flour 4407	>99.9	71.0			
Yellow Corn Bran 8000	65	5.0			
Torit Filter			97.7	82.9	71.0
4D Filter			100	97.0	85.9

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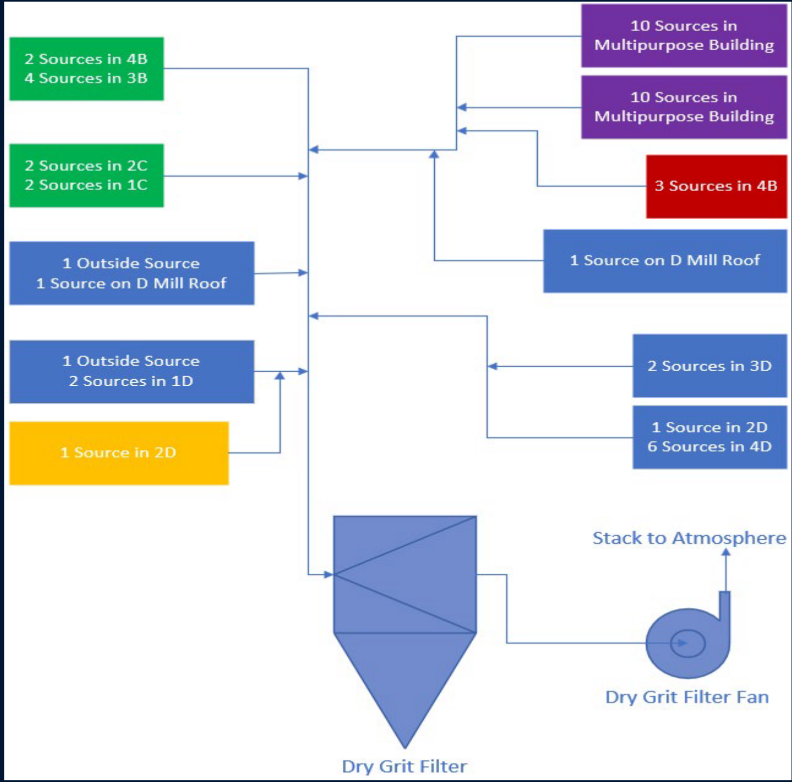
PROCESS HAZARD RECOGNITION

2) Equipment Interconnectivity



- The CSB concludes that Didion did not recognize the propagation hazard that interconnecting numerous pieces of equipment presented.
- NFPA 61 (2008 through 2020 editions) also references NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Mists, and Particulate Solids regarding duct systems for air-material separators. NFPA 91 (2010-2020 editions) requires: *Ducts from a single piece of equipment or from multiple pieces of equipment interconnected on the same process stream shall be permitted to be manifolded. [...] Ducts from nonassociated pieces of equipment shall be permitted to be manifolded provided that each duct is equipped with an isolation device prior to manifolding in accordance with NFPA 69, Standard on Explosion Prevention Systems [49, p. 11] [50, p. 13] [51, p. 7.1.9.2].*

PROCESS HAZARD RECOGNITION

3) Dust collector Explosibility

From nclabor.com page 11 table 1 http://www.nclabor.com/osha/etta/indguide/ig43.pdf

Lower explosive limit for corn dust.

55 grams/M3

Granulation	1	2	3	Average
40 Wire	95.2%	96.0%	93.2%	94.8%
Pan	4.8%	4.0%	6.8%	5.2%

NFPA 61

3.3 General Definitions.

3.3.1* Agricultural Dust. Any finely divided solid agricultural material 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) that presents a fire or explosion hazard when dispersed and ignited in air.

3.3.2* Air-Material Separator (AMS). A device designed to sepa-

Material flow	
17500	Lb/hr gross mass flow rate thru 6 filters
910	Lb/hrflow rate of less than 40 wire
910*453.59237=	
412,769.06	Grams/hr
Air flow	
63549	acfm
63549*0.028316846592*60=	
107970	cubic meters/hr
412769.06	/107970.437=
3.82	grams/M3
7.0%	Percentage of lower explosive limit.

- The calculation of maximum dust concentration was calculated as 12% of MEC within the air streams
- Didion calculated the dust concentration inside each dust collector by:

.measuring or calculating an air flowrate supplying each dust collector
.measuring or calculating solid particle flowrate in the ductwork feeding each dust collector;
.removing any particles sized greater than 425 microns from the calculation;
.using the resulting airflow and particle flow values to calculate a dust concentration in the supply duct to the dust collector, and .comparing the resulting concentration to the MEC

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Fugitive Dust Management

The CSB concludes that Didion's Monthly Sanitation Inspection had ineffective housekeeping practices and allowed unacceptable levels of dust layer As a result, secondary dust explosions fueled by fugitive dust led to building collapse and multiple injuries and fatalities.

- The housekeeping program was the site's sanitation program.
- Employees performing the inspections did not had a clear understanding of dust accumulation risk in the Monthly Sanitation Inspections- the only mention of OHSA's 1/8 inch at priority.
- Master sanitation relied on HACCP (Hazard Analysis and Critical control Points)
- Didion's HACCP did not contain any analyses of combustible dust hazards or scenarios

Examples of fugitive dust accumulations, (A) approximately three months before the incident, (B) approximately two weeks before the incident, and (C) less than 24 hours before the incident.

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Standards for compliance

Territory	Regulations Name	Methodological Assessment	Comment
European Union	ATEX Directive 1999/92/EC (ATEX 153) 	Explosion Protection Document	Minimum requirement for all EU members states on explosion safety for plant owners
Singapore	SS 667:2020	Code of practice for handling, storage and processing of combustible dust	This code sets out requirements and recommendations to help in the prevention of fires and explosions that could result from the ignition of suspended, fine solid particulates within an enclosure or building
USA	NFPA 654, OSHA 	DHA (Dust Hazard Analysis)	NFPA and OSHA do not provide a standard or regulation, there is no new legal obligations. Aim to assist employers in providing a safe and healthful workplace.

Most Common Findings

- No action on the dust explosion assessments and recommendations
- Lack of combustible dust training
- Inadequate Standard Operating Procedures (SOPs) and Preventative Maintenance (PMs)
- Equipment / Explosion protection deficiencies
  - No protection
  - Undersized protection
  - Incorrect orientation/installation

Training

- NFPA 652, Chapter 8.8:
  - *8.8.2 – General safety training and hazard awareness training for combustible dusts and solids shall be provided to all affected employees.*
  - *8.8.3 – Refresher training shall be provided as required by the AHJ and as required by other relevant industry- or commodity-specific NFPA standards.*
- If the combustible dust training is being completed, ensure it is formally documented.

Standard Operating Procedures (SOPs)

- NFPA 664, Chapter 8.3:
  - *8.3.1 – The owner/operator shall establish written procedures for operating its facility and equipment to prevent or mitigate fires, deflagrations, and explosions from combustible particulate solids.*
  - *8.3.2 – The owner/operator shall establish safe work practices to address hazards associated with maintenance and servicing operations.*
  - *8.8.3 – A periodic walk-through review of operating areas shall be conducted, on a schedule established by the owner/operator, to verify that operating procedures and safe work practices are being followed.*

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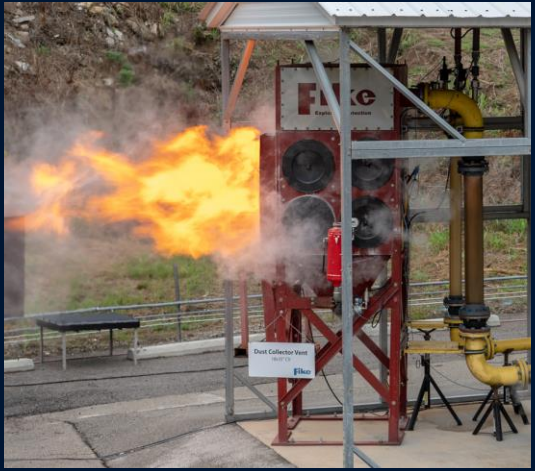
Preventative Maintenance (PM)

- NFPA 652, Chapter 8.7.1: *Equipment affecting the prevention, control, and mitigation of combustible dust fires, deflagrations, and explosions shall be inspected and tested in accordance with the applicable NFPA standard and the manufacturers' recommendations.*
- NFPA 652, Chapter 8.7.2: *The inspection, testing, and maintenance program shall include the following:*
  1) *Fire and explosion protection and prevention equipment in accordance with the applicable NFPA standards*
  2) *Dust control equipment*
  3) *Housekeeping*
  4) *Potential ignition sources*
  5) *Electrical, process, and mechanical equipment, including process interlocks*
  6) *Process changes*
  7) *Lubrication of bearings*

Deflagration Venting Deficiencies

- NFPA 68, Chapter 6.6.1 – *The material discharged from an enclosure during the venting of a deflagration shall be directed outside to a safe location.*
- Common findings:
  - No explosion protection.
  - Deflagration vents located inside buildings, directed into the building.
  - Deflagration vents located inside buildings ducted to the outside incorrectly.
  - Deflagration vents without adequate space to properly relieve.
  - Deflagration vents directed to potentially occupied locations.
  - Undersized deflagration vents.



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Explosion Suppression Deficiencies

- Common findings:
  - Not conducting the required quarterly inspections on the system.
  - Not providing training to maintenance and other affected employees that would have to work on the protected piece of equipment.

Isolation Valve & Abort Gate Deficiencies

- Common findings:
  - Isolation valves not certified by a recognized testing organization.
  - Abort gates pointed downwards to potentially occupied locations.

Recommendations

- If the DHA has not been conducted, have the DHA completed.
- If the DHA has been conducted, prepare an action plan with timelines and responsibilities for addressing the findings of the DHA.
- When installing new processes and/or equipment, have a DHA completed on the proposed design.
- Training, training, and more training.
- Review Standard Operating Procedures (SOPs) for accuracy and ensure employees are trained on the SOPs.
- Review Preventative Maintenance (PM) Program to ensure it is accurate, complete, and addresses the requirements of NFPA.
- Check explosion protection systems to ensure they are installed and inspected in accordance with the requirements of NFPA 68 and/or 69.
- Maintain documentation on explosion protection systems that identify the certifications and sizing of equipment. If you have old systems or used equipment that came with existing protection, have that inspected by an explosion protection vendor to ensure it is appropriate and meets NFPA 68 and/or 69.

THANK YOU!

Questions?

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